

A 3D cutaway diagram of a particle accelerator, likely the Super Proton Synchrotron (SPS) at CERN. The diagram shows a complex arrangement of vacuum chambers, magnets, and beam pipes. A central beam pipe is highlighted in green, with other components in red, blue, and yellow. The background is a light blue gradient.

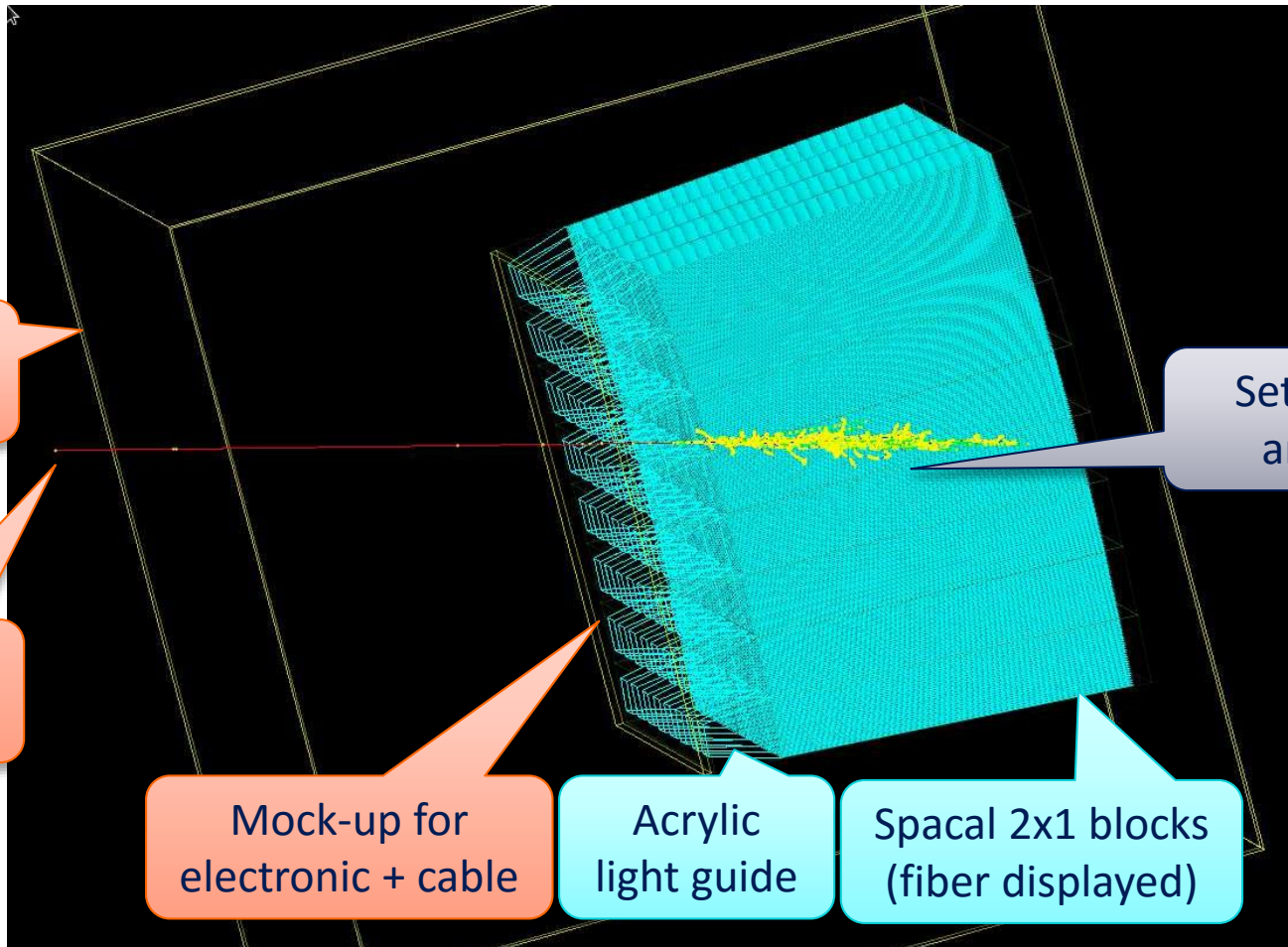
SPACAL test beam data & simulation need

Jin Huang (BNL)

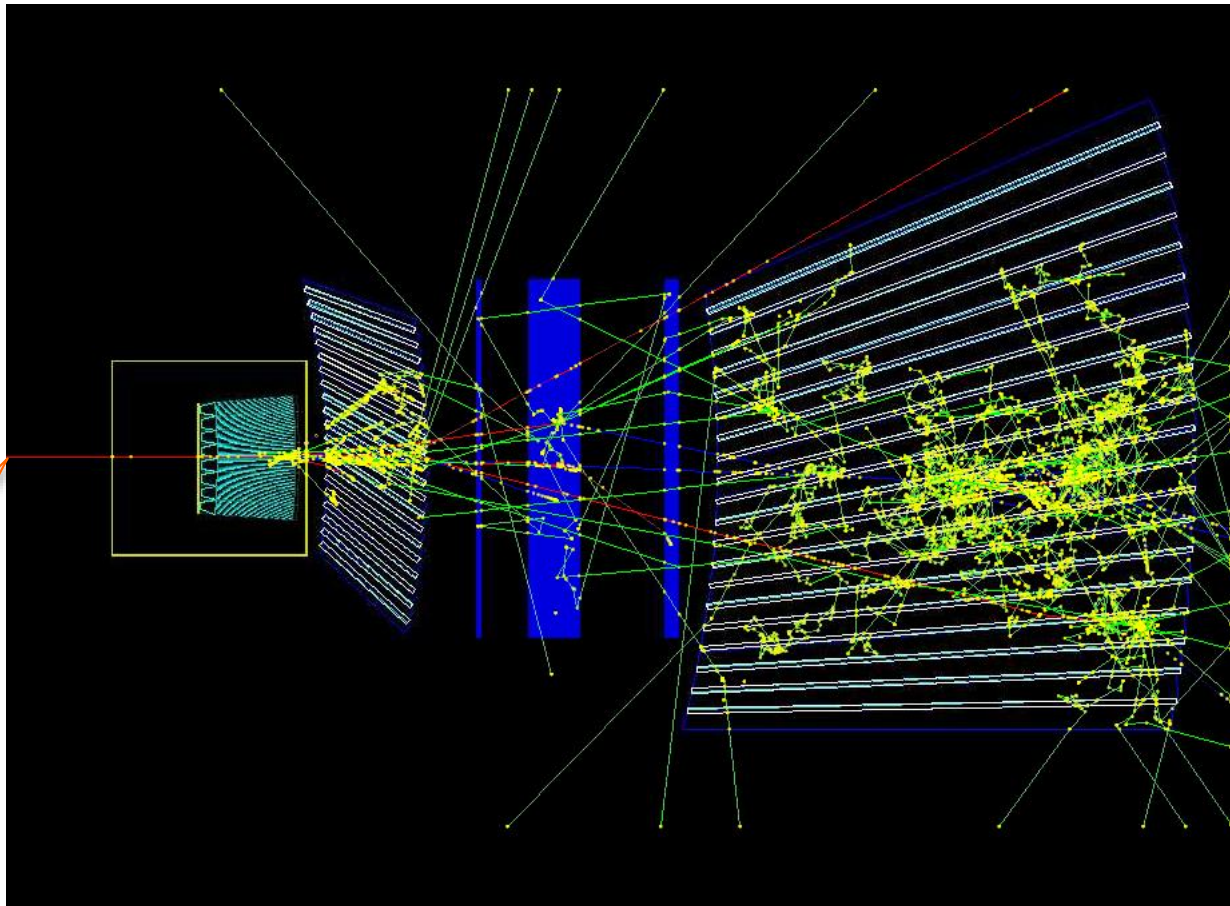
2016 SPACAL test beam simulation

- ▶ Read to use:
 - SPACAL in 2016 setup including light guide and enclosures
 - Scintillation modeling and digitization
 - Analysis macros
- ▶ Related Pull request merged/being merged:
 - Nightly-code base:
<https://github.com/sPHENIX-Collaboration/coresoftware/pull/121>
 - Geometry database:
<https://github.com/sPHENIX-Collaboration/calibrations/pull/8>
 - Simulation macros:
<https://github.com/sPHENIX-Collaboration/macros/pull/17>
 - Analysis macros:
<https://github.com/sPHENIX-Collaboration/analysis/tree/master/Prototype2/EMCal/macros>
- ▶ Request:
 - Help to verify settings
 - Help to run more simulations for each planned data point in test beam

What being simulated



And with HCal too



Test beam
(32 GeV π^-)

More on request 1: Final simulation tune

► Digitization

- Light yield: SiPM Pixel / GeV (current: 500)
- Gain in ADC units (high/low gains): ADC/SiPM Pixel (current: 1)
- Noise in ADC units (high/low gains): Gauss width in ADC channels (current: 1)
- Relative light collection efficiency (current: no-fiber-fiber variation)

► Tower construction

- Final hole pitch (current: 1.01 mm)
- Average fiber – surface fiducial distance (current: 130 μ m)
- Average module dimensions (30 x 52 holes + fiducial volume)

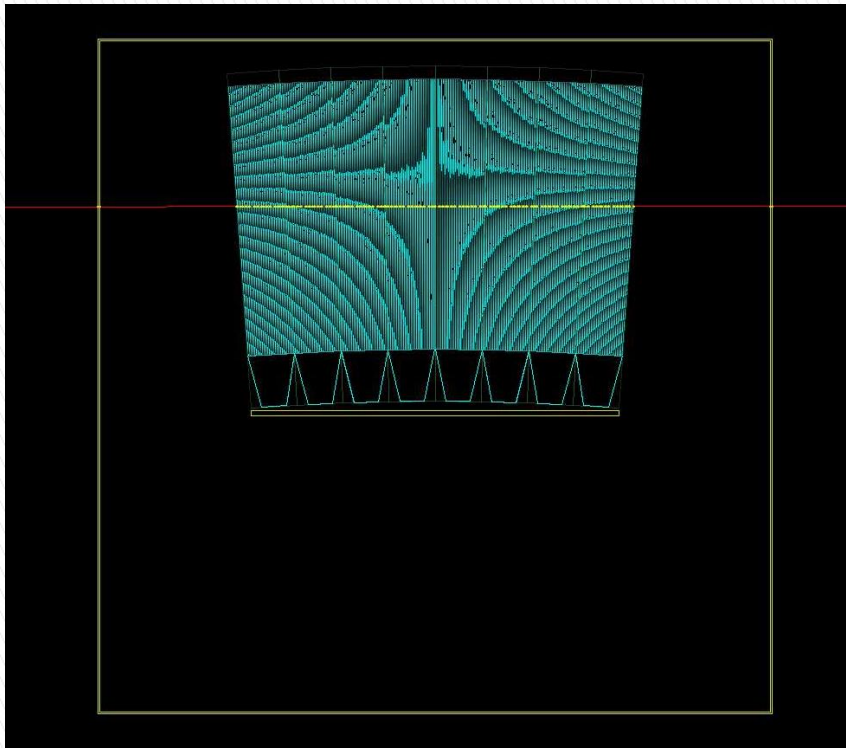
► Enclosure

- Average material for cable + PCB (current: 2.5mm x G10)
- Average material for enclosure (current: 40 mil x G10)

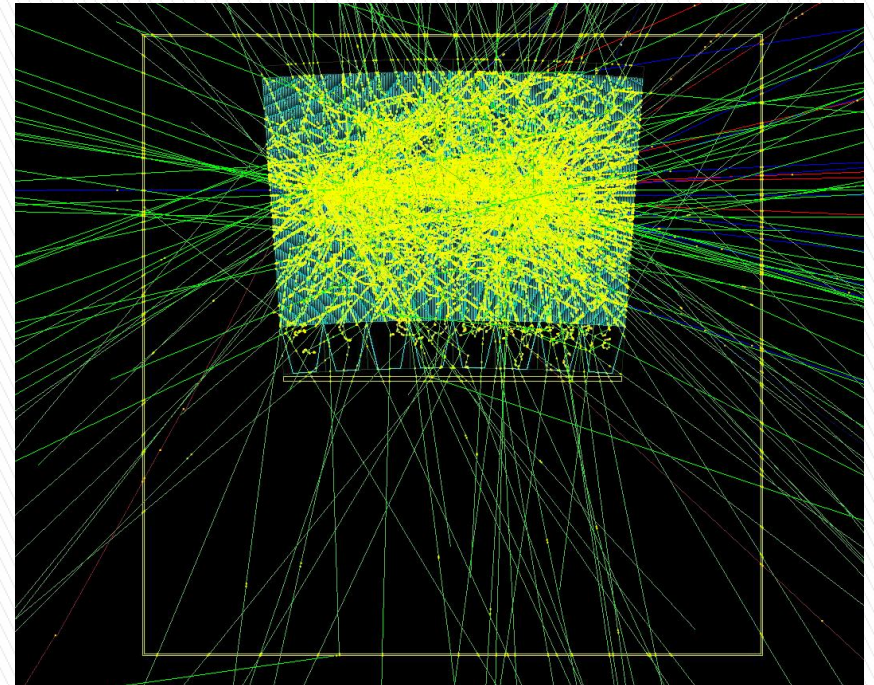
120 GeV proton calibration



Study1: 120 GeV proton calibration



Some proton MIP through

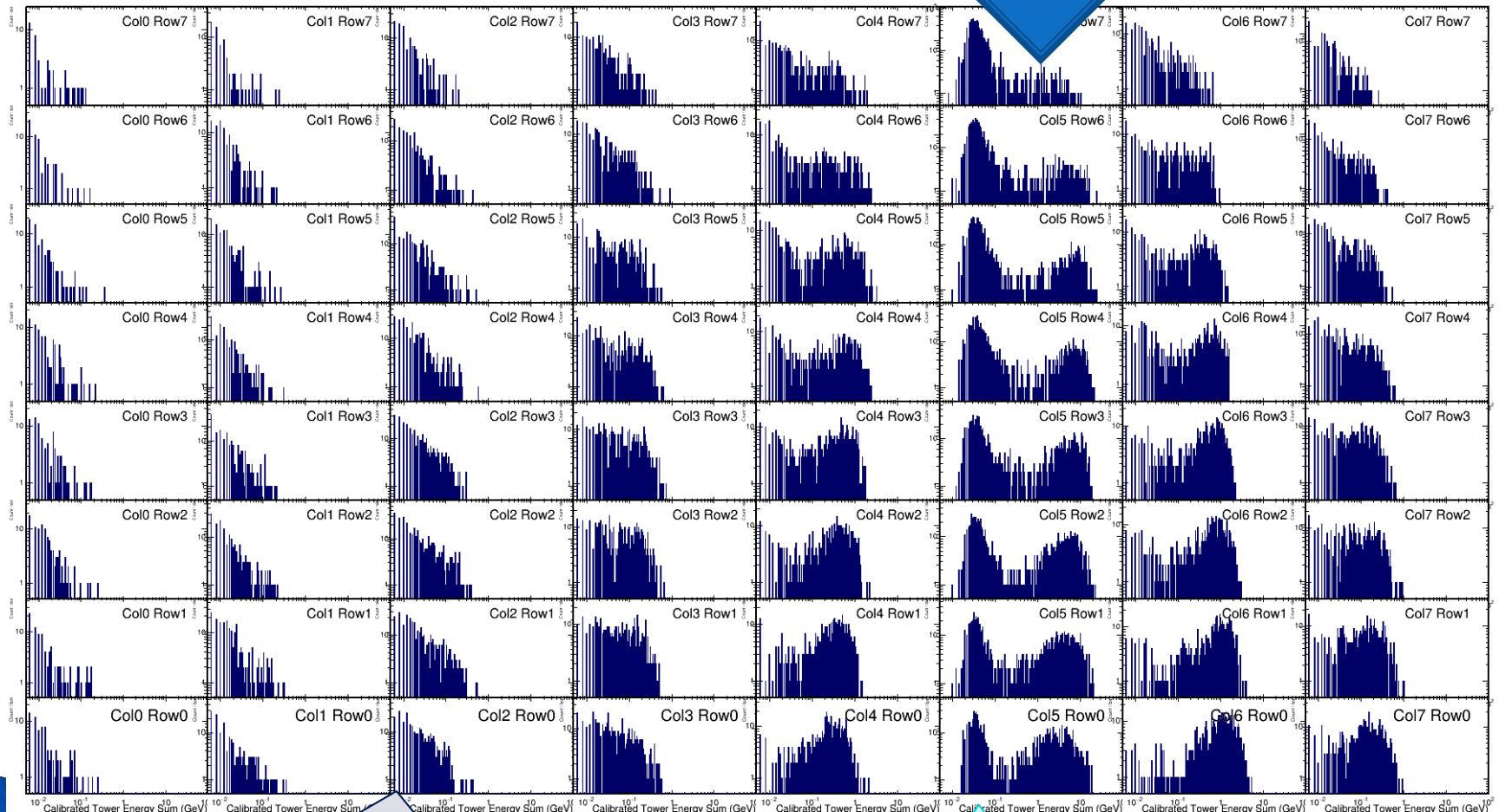


Though many init a shower as
SPACAL is > 1 interaction length

And measurement:

Channel map as viewed from the readout side

120 GeV proton



ADC discretization, as measured
in 60ns/3-samples sum

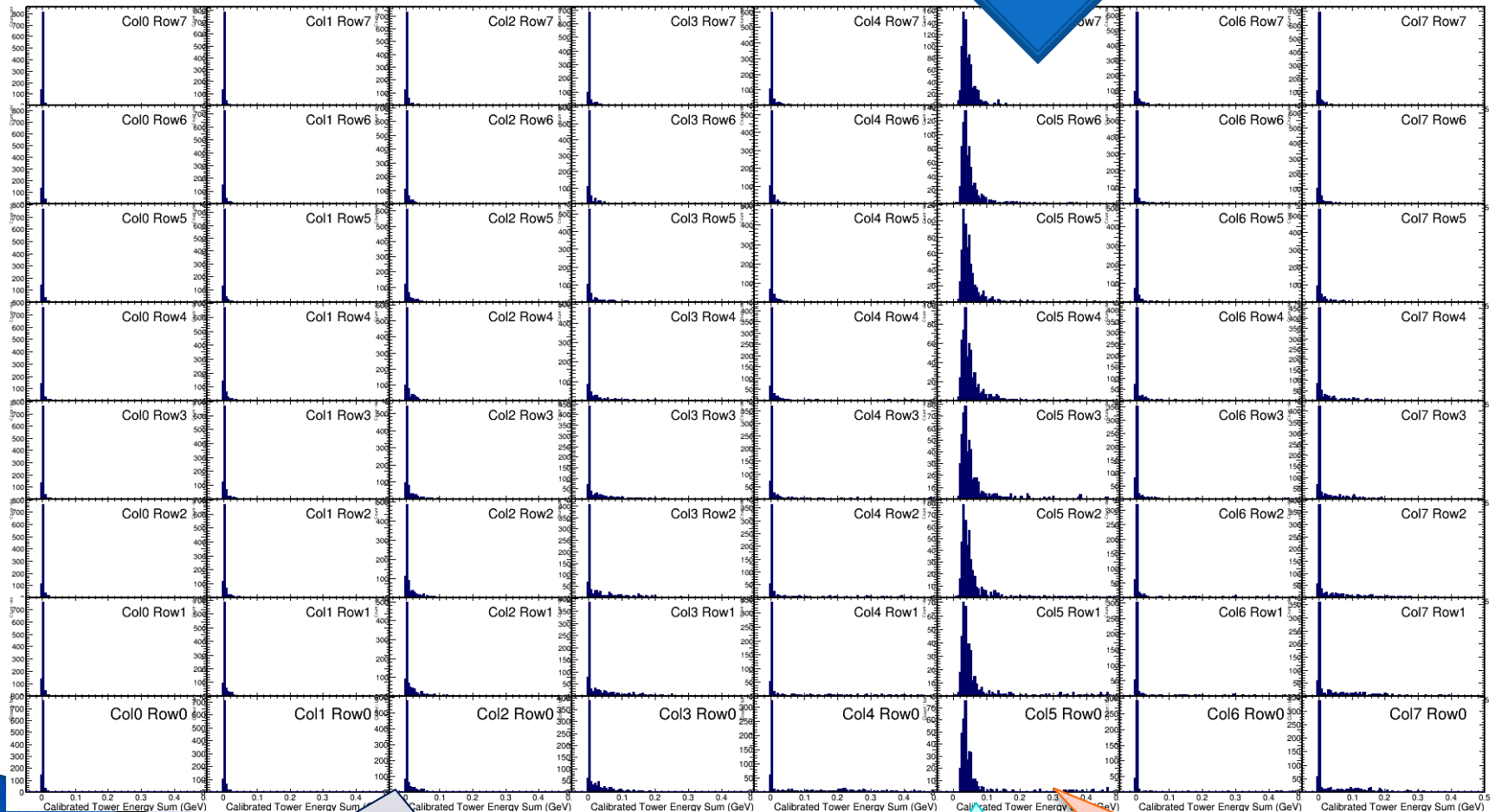
MIP
~ 30 MeV

Shower ~ a few
GeV

High gain zoom-in

Channel map as viewed from the readout side

120 GeV proton

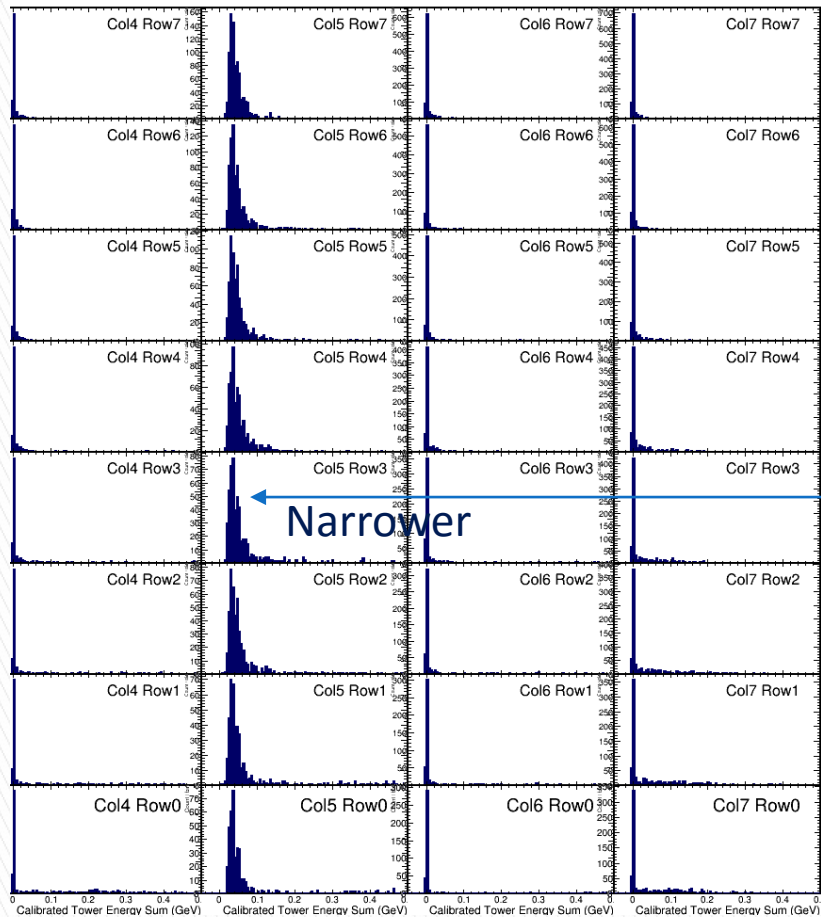


ADC discretization, as measured
in 60ns/3-samples sum

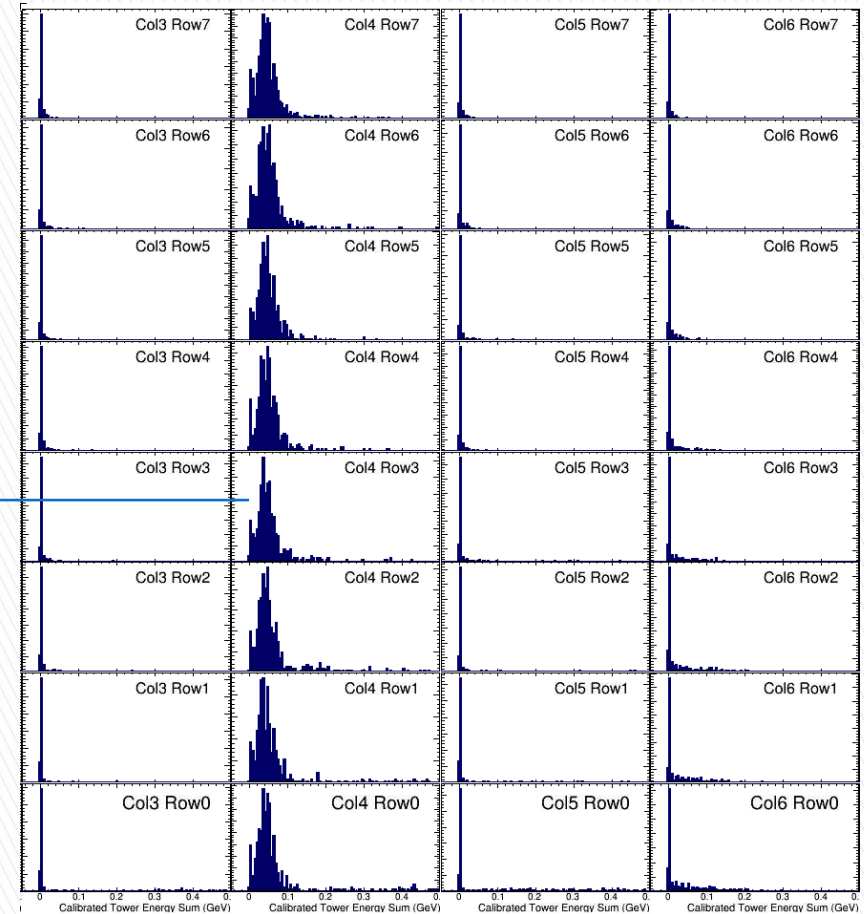
MIP

Shower

Shape depends on orientation too



Rotates setup horizontally by
100mrad

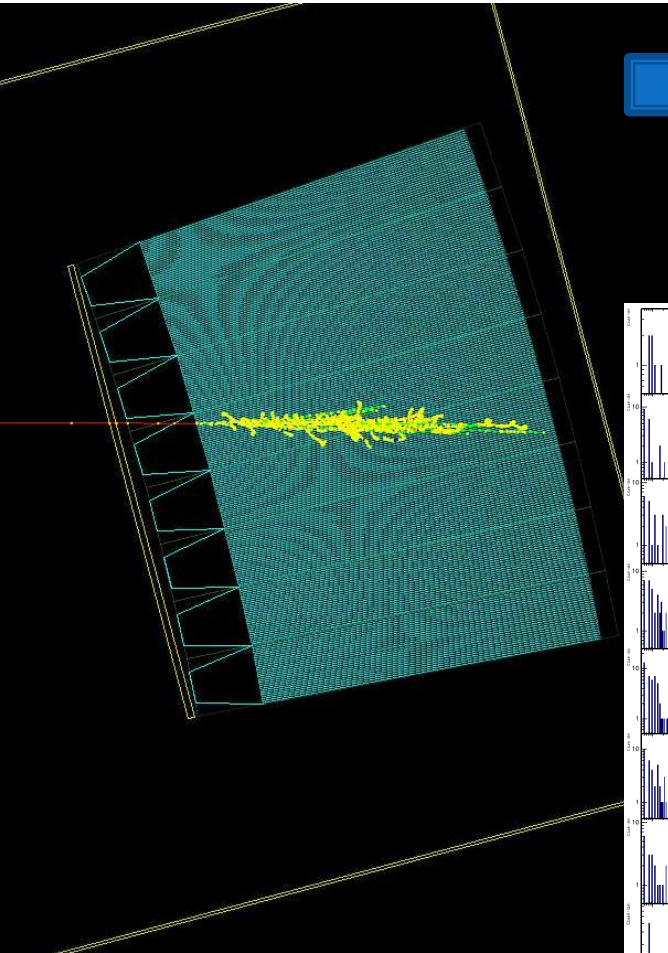


Default track (fiber pitch
observed by MIP)

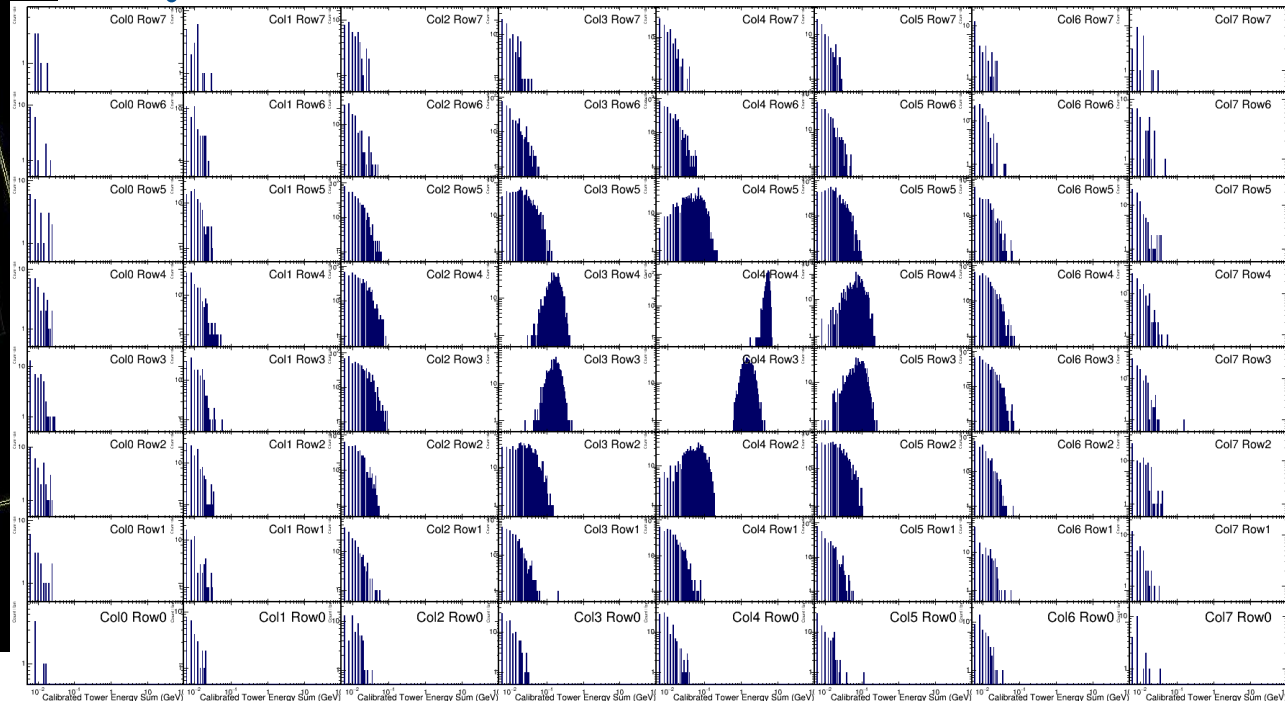
Resolution and Line shapes



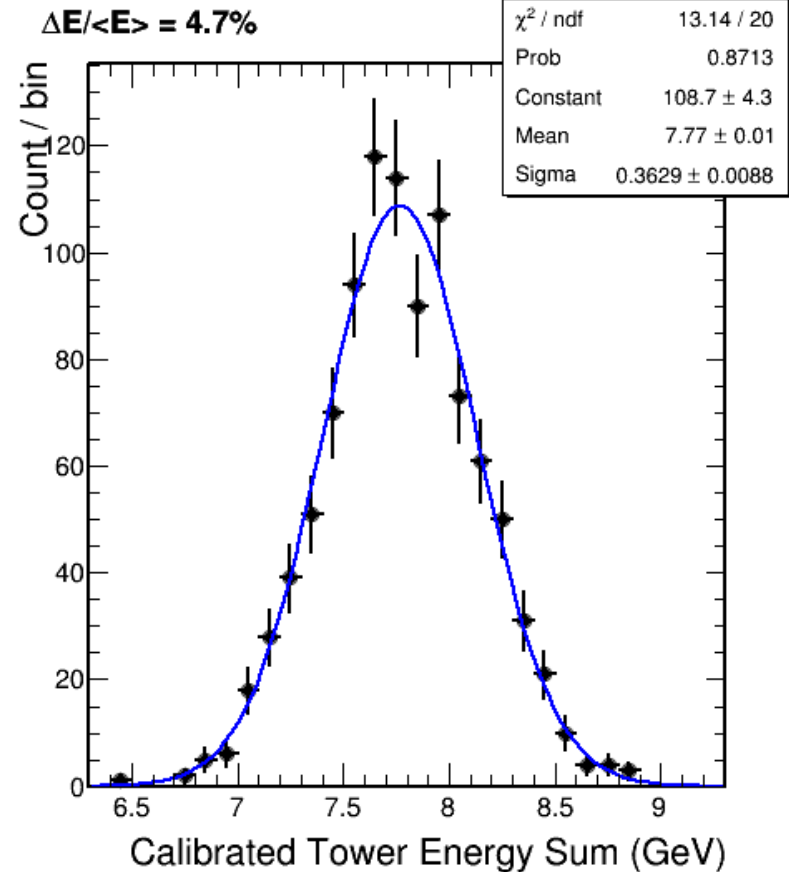
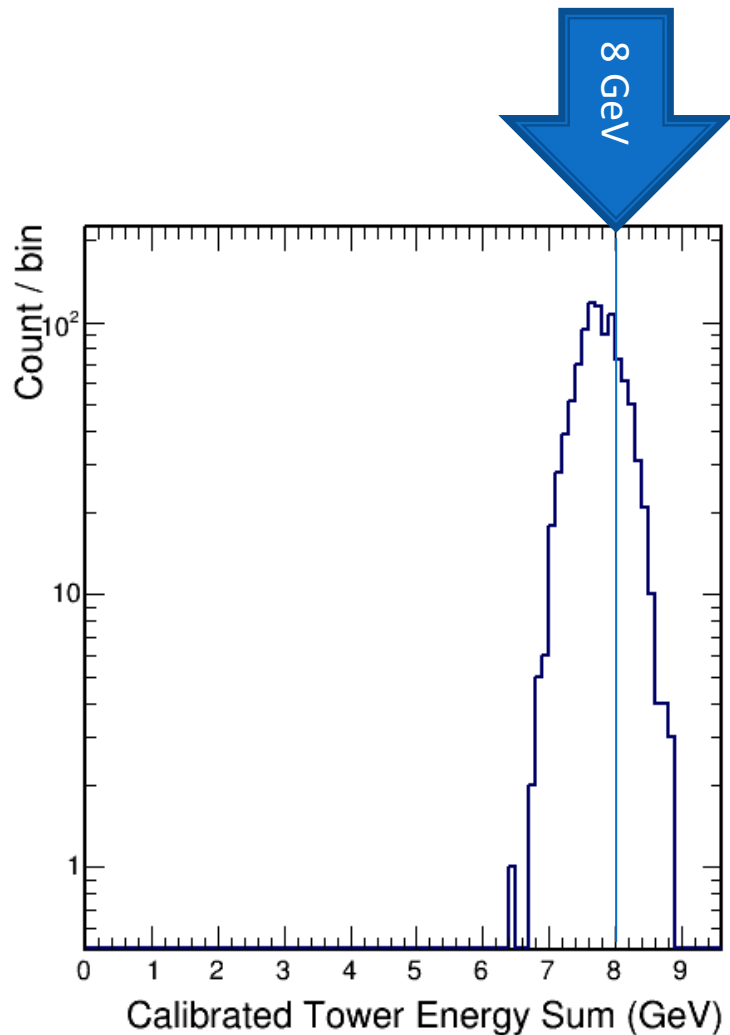
8 GeV electron with module tilted 300mrad/15 degrees



Digitize and calibrate

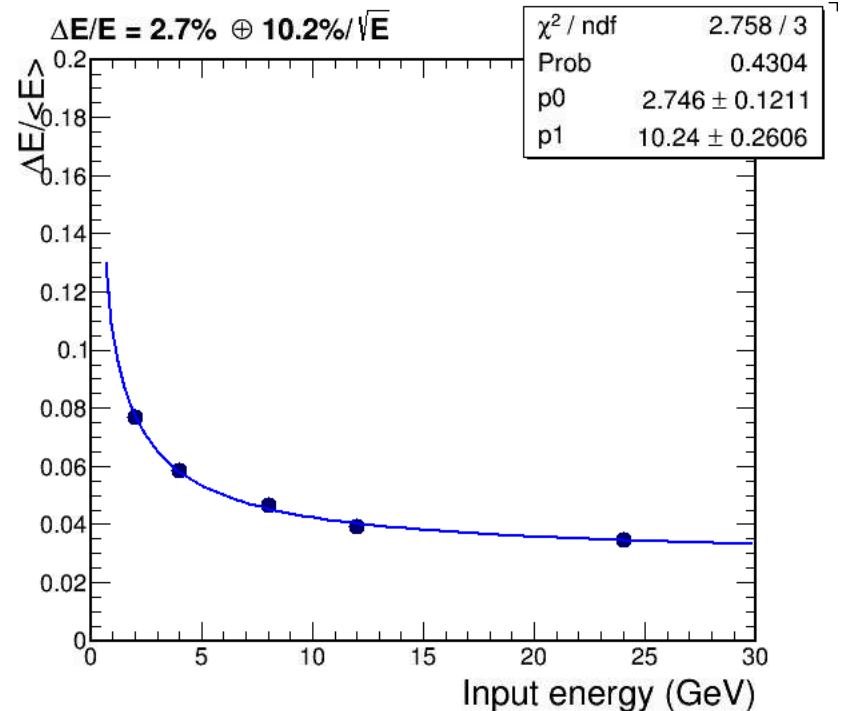
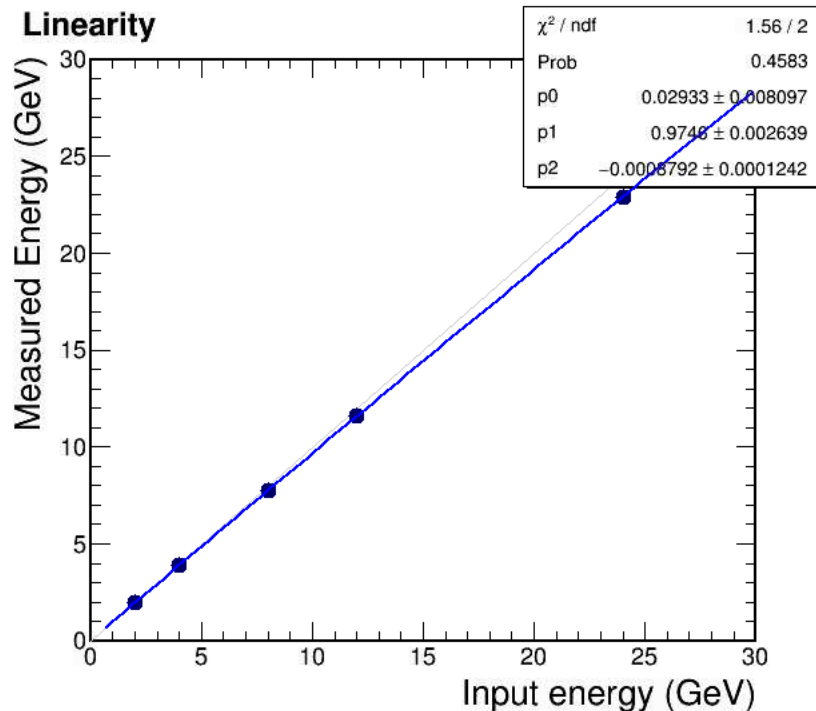


8 GeV electron line shape



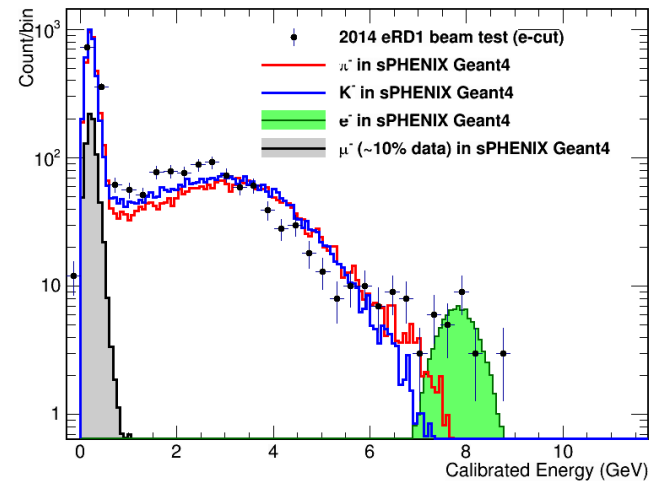
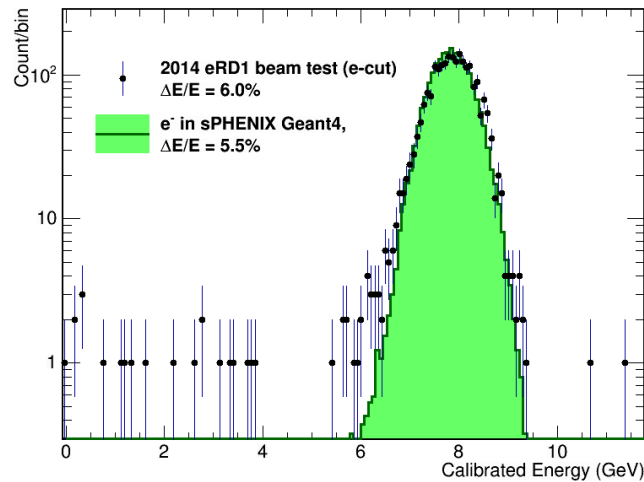
Linearity and resolution summary

- Note: before finalizing geometry and digitization



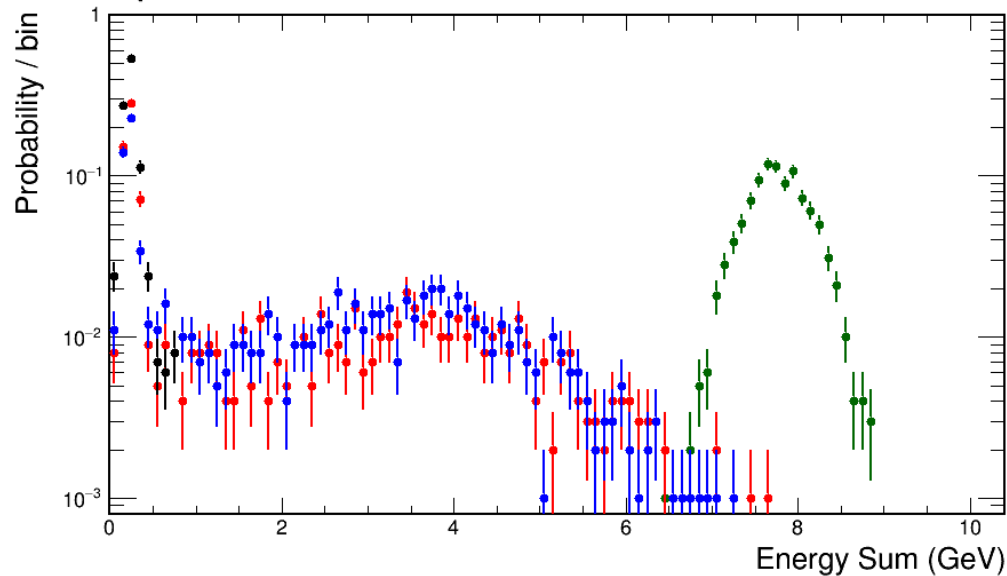
Line shapes – 8 GeV

2014 UCLA



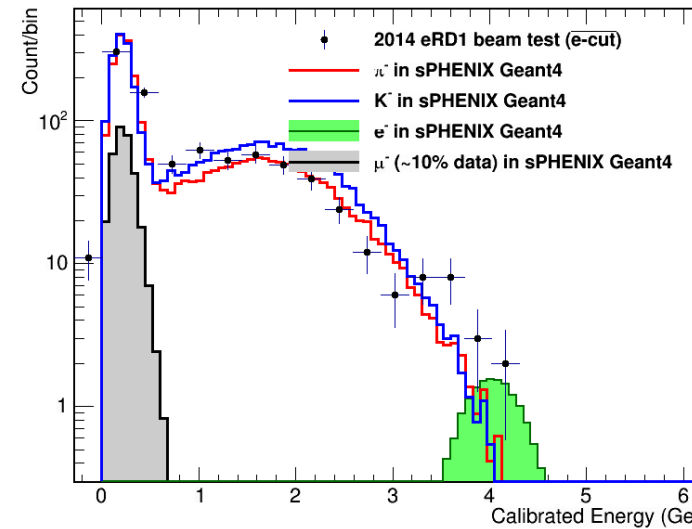
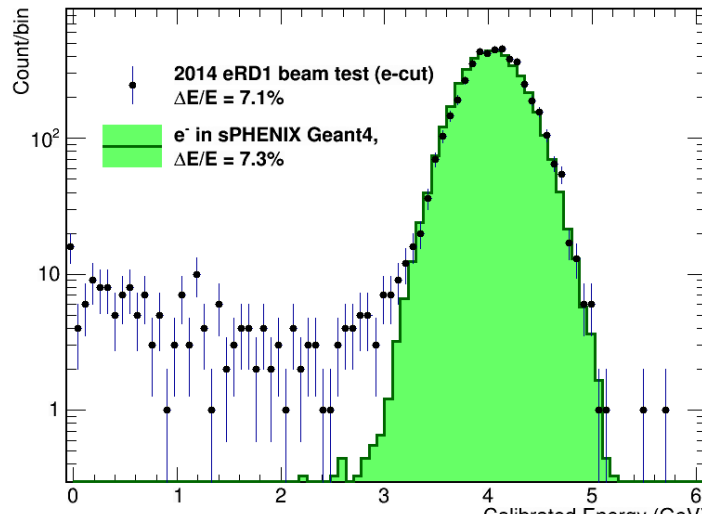
2016 sPHENIX

Line shape for 8.0 GeV beam



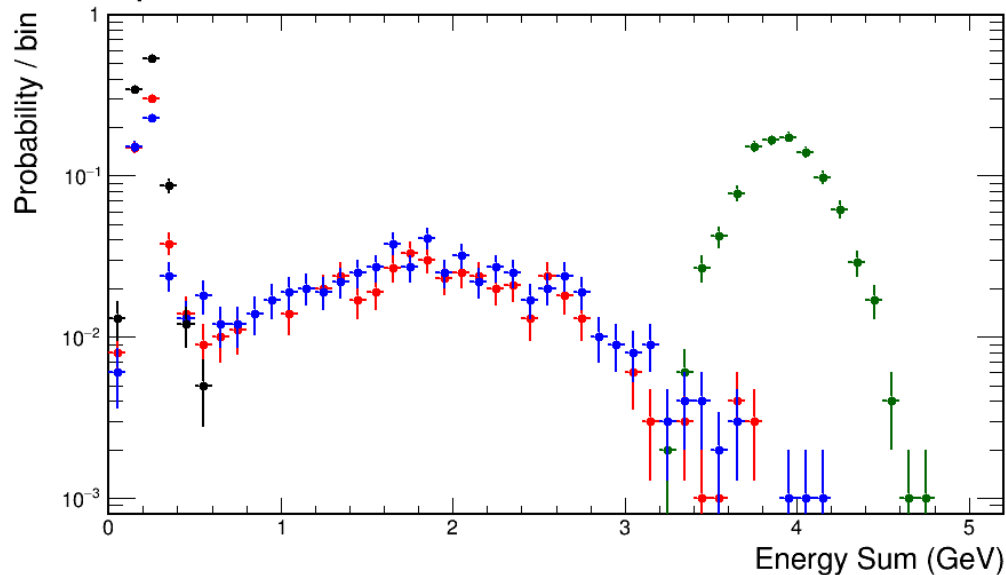
Line shapes – 4 GeV

2014 UCLA



Line shape for 4.0 GeV beam

2016 sPHENIX

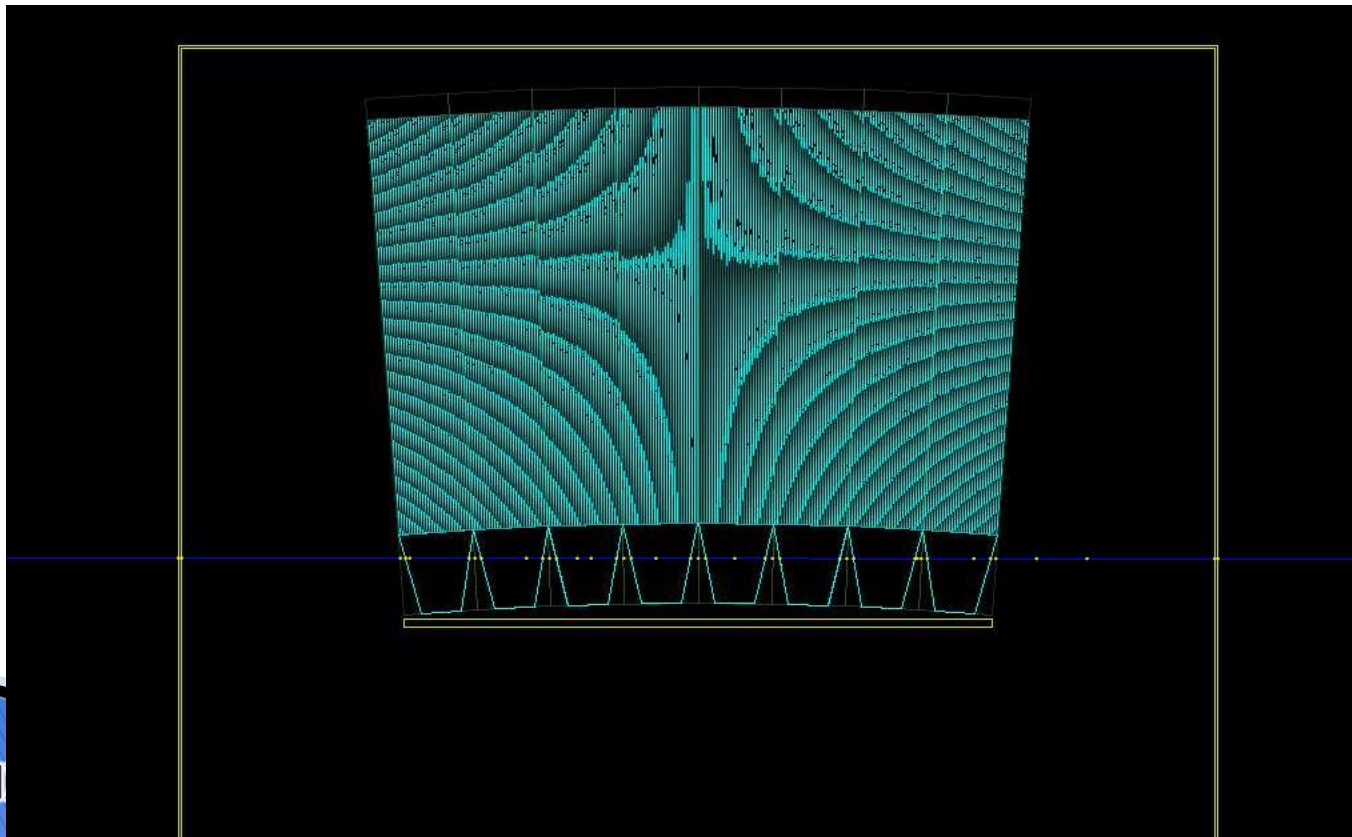


Cherenkov test in light guide



Discussion: Cherenkov test in light guide

- ▶ Quantify Cherenkov light with MIP through light guide
- ▶ Example setup: 120 GeV proton beam with SPACAL rotated by 90 degree



Extra information on 2014 test beam



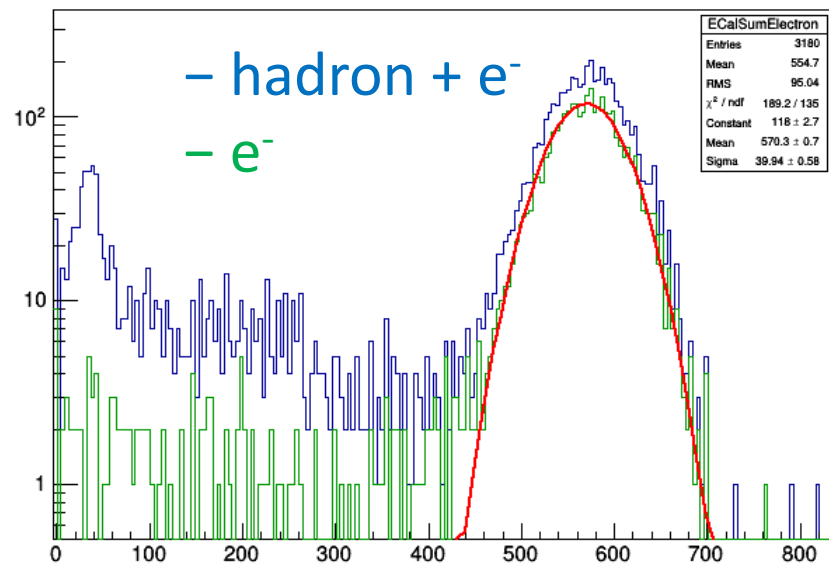
What we have/haven't implemented

- ▶ Beam momentum spread, position spread and multi-species
 - 2.4% for 8 GeV/c beam, 2.7% for 4 GeV/c beam
- ▶ Active volume
 - Tunable size/matrix/fiber specifications/fiducial region
- ▶ Baseline simulation configuration, which is also tunable
 - **Hadronic model**: QGSP_BERT_HP
 - **Light production**: Geant4 default Birk model (G4EmSaturation::VisibleEnergyDeposition)
 - **Group Geant4 hits** into fibers then into towers
 - Possible to use measured fiber-fiber light variation map
 - **Digitalization** with test beam performance:
 - photon fluctuation (500p.e./GeV, Poisson model)
 - Pedestal noise (2ADC)
 - Zero suppression of (4ADC)
- ▶ Need to finalize geometry with Hcal simulation

Last study: eRD1 2014 1D proj. SPACAL

- ▶ Obtained eRD1 2014 beam test geometry and data with many help from Oleg Tsai, Alex Kiselev and Craig Woody
 - Diff with sPHENIX test beam device: fiber choice, SPACAL vendor, electronics
- ▶ Implemented in Geant4 -> SPACAL towering -> digitization

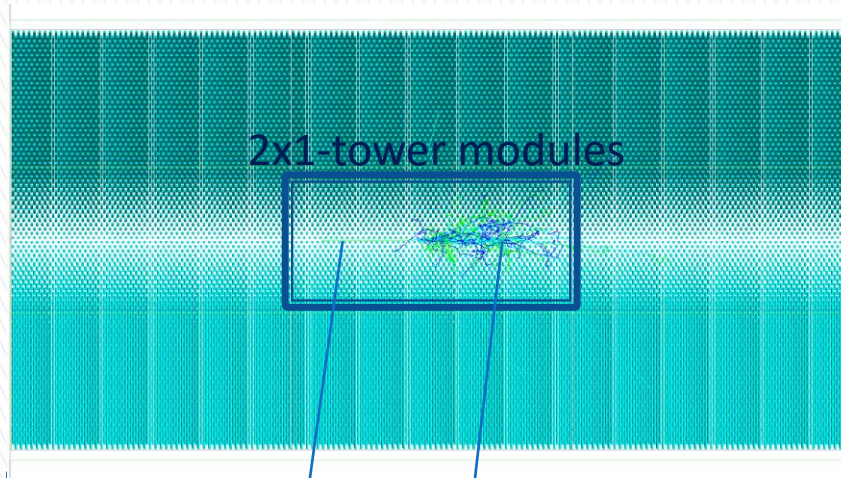
SPACAL prototypes in 2014 Fermilab beam test



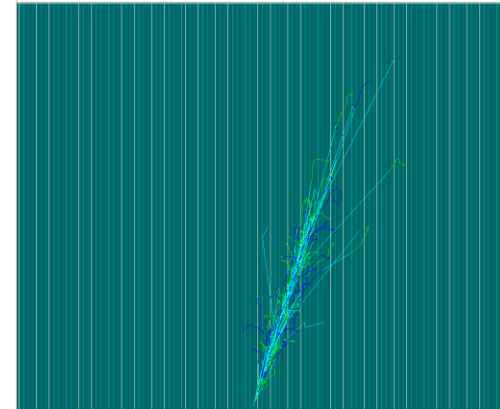
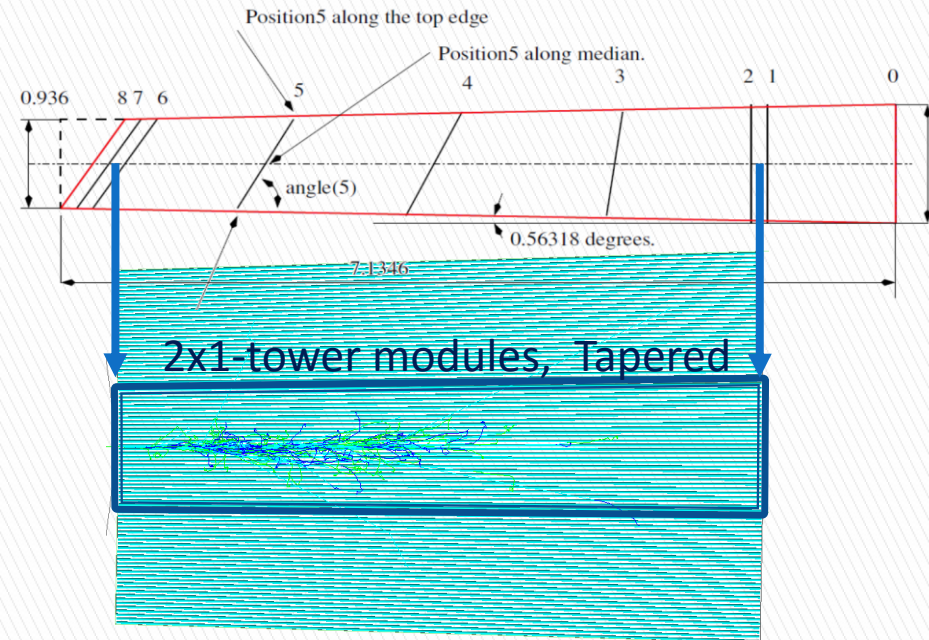
Courtesy : O. Tsai (UCLA)

Test beam in G4

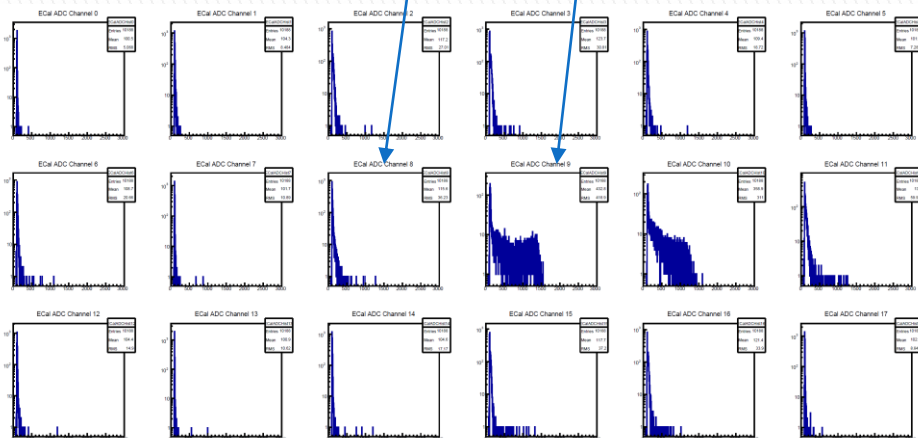
1D fiber, parameter tunable



Particle view
(half cm front Al cover not shown)

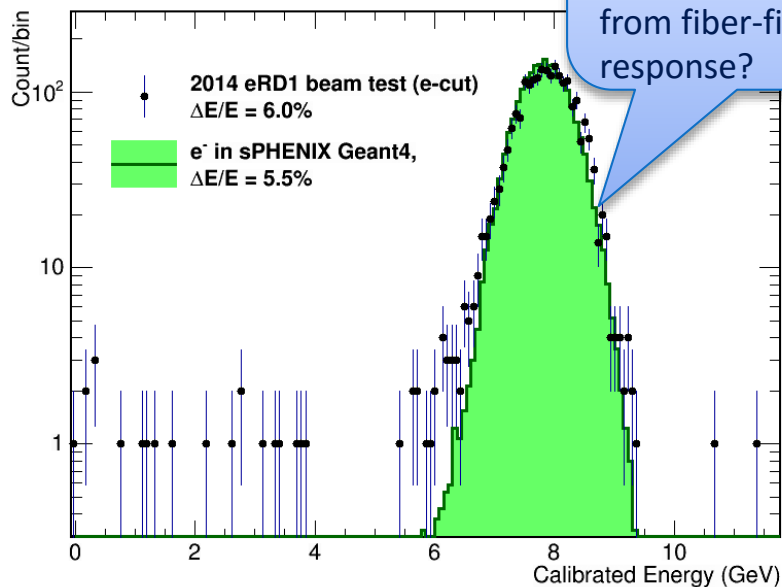


Side views
(17 degree indenting as in test beam, 2.4-2.7% energy spread and half-cm front Al cover not shown)

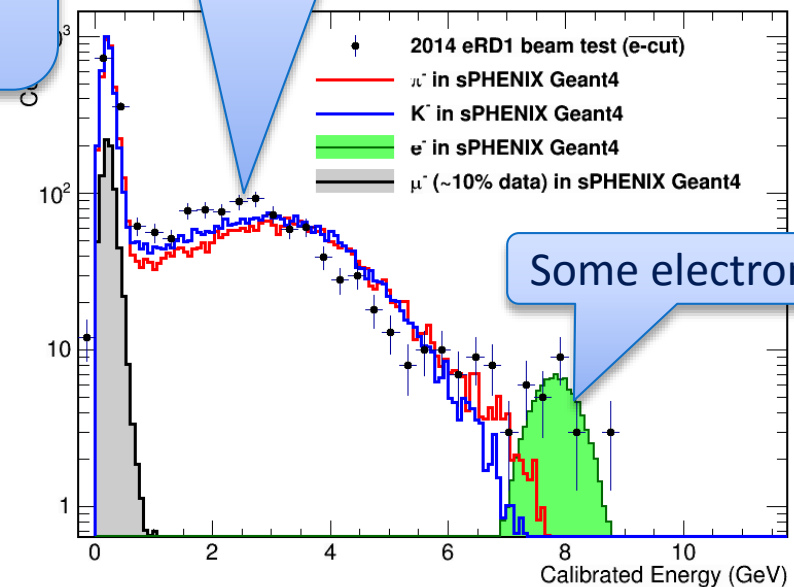


Beam test data, eRD1 2014

Test beam comparison: 8 GeV beams shower in Geant4 VS data



Very good matching in line shape.
Data: slightly more fluctuation (<10% rel.) from fiber-fiber response?



Less response in data?
Proton component?

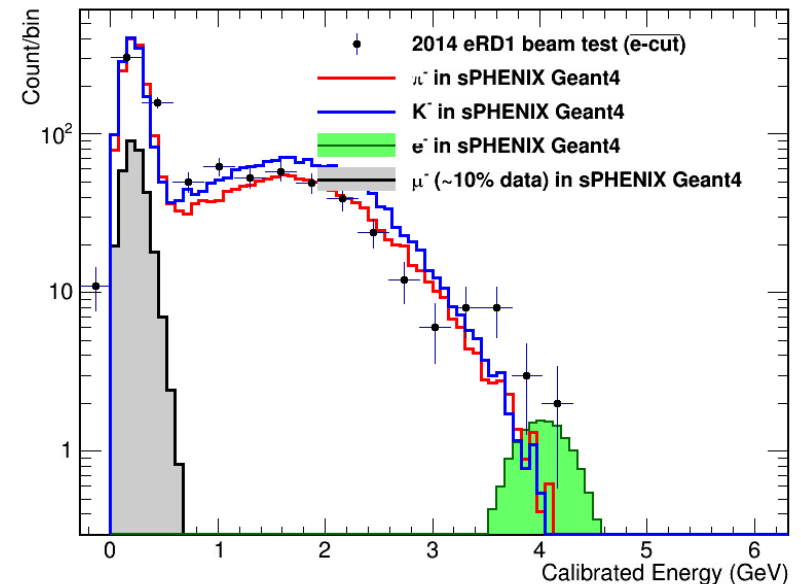
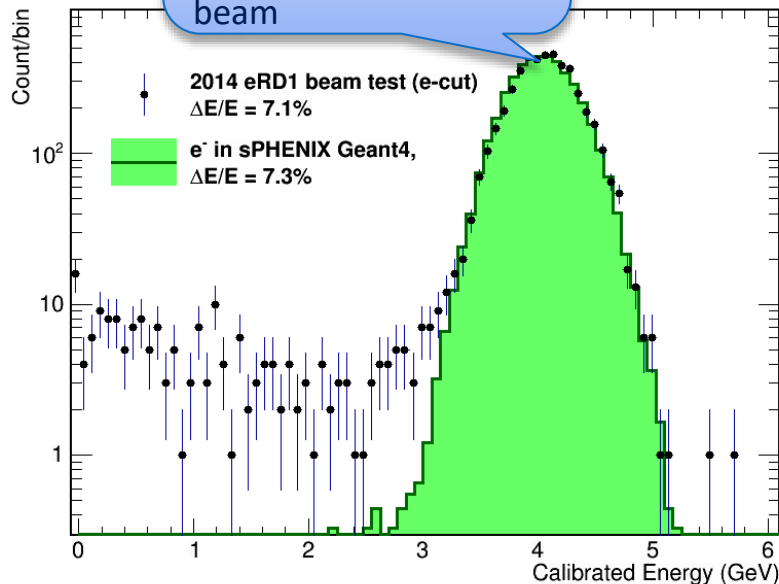
Some electron left

Full Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (2ADC), photon fluctuation (500e/GeV), NO fiber/fiber response

Test beam comparison:

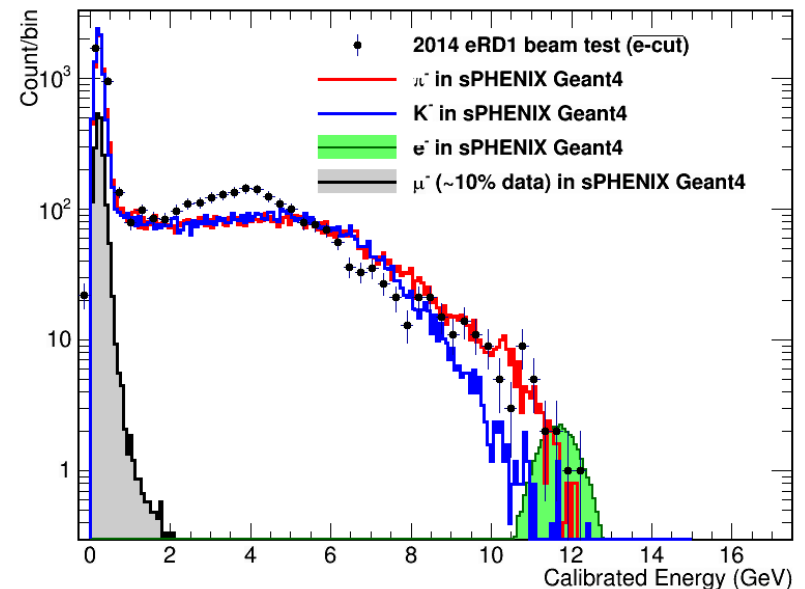
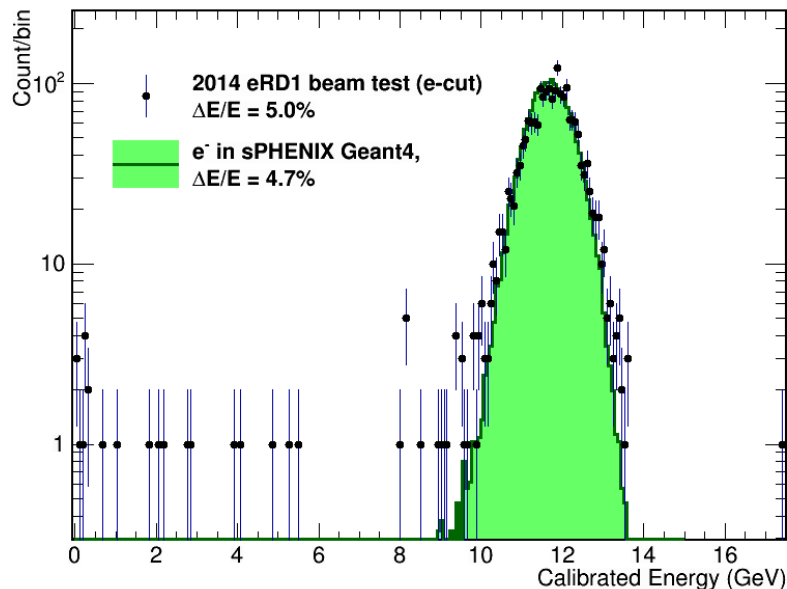
4.12 GeV/c beams shower in Geant4 VS data

Linearity reproduced
with energy scale
calibration from 8GeV
beam for 4.12 GeV/c
beam



Full Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (2ADC), photon fluctuation (500e/GeV), NO fiber/fiber response

Test beam comparison: 12 GeV/c beams shower in Geant4 VS data



Full Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (2ADC), photon fluctuation (500e/GeV), NO fiber/fiber response

Needed from test beam: beam data

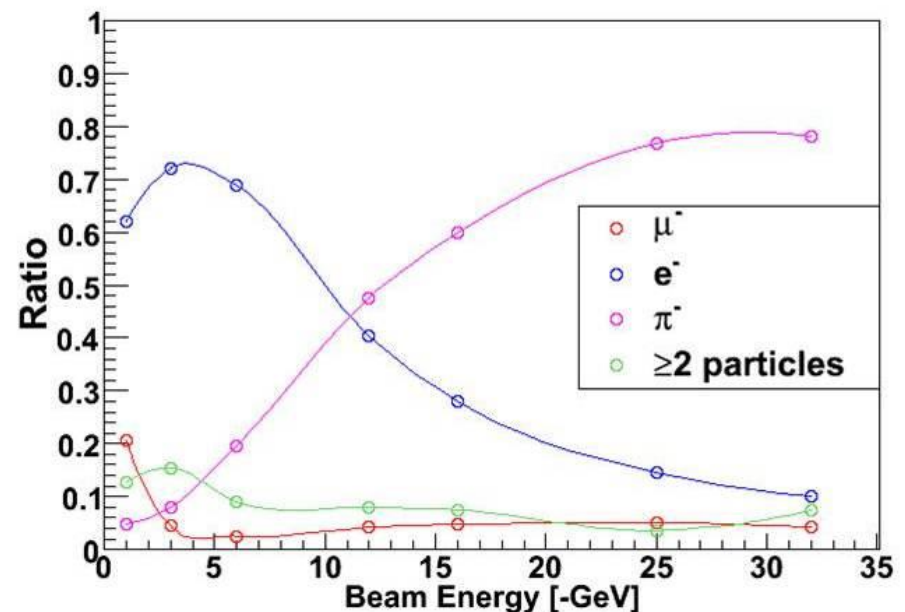
- ▶ Need to verify composition not significantly changed
- ▶ What about proton/anti-proton composition in “pion”?

SPHENIX beam test, Liang, Xiaochun and John H.

Test Beam Composition:

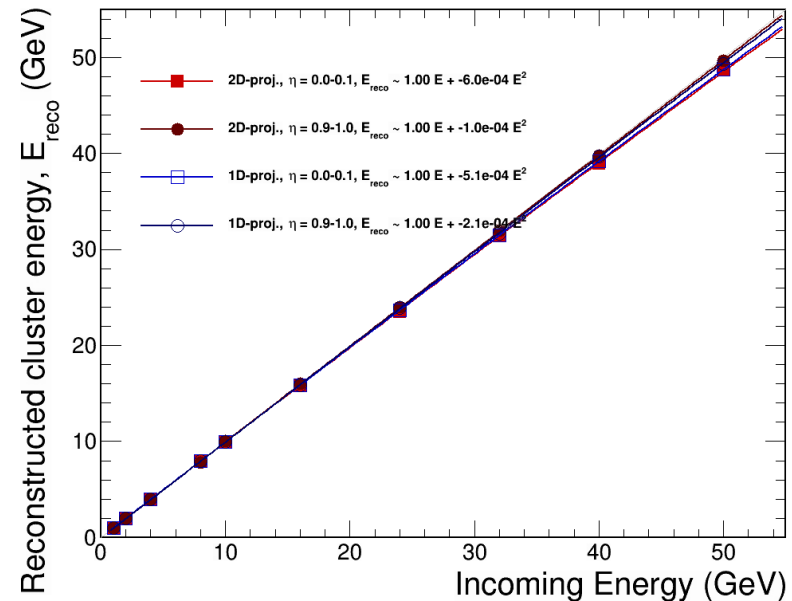
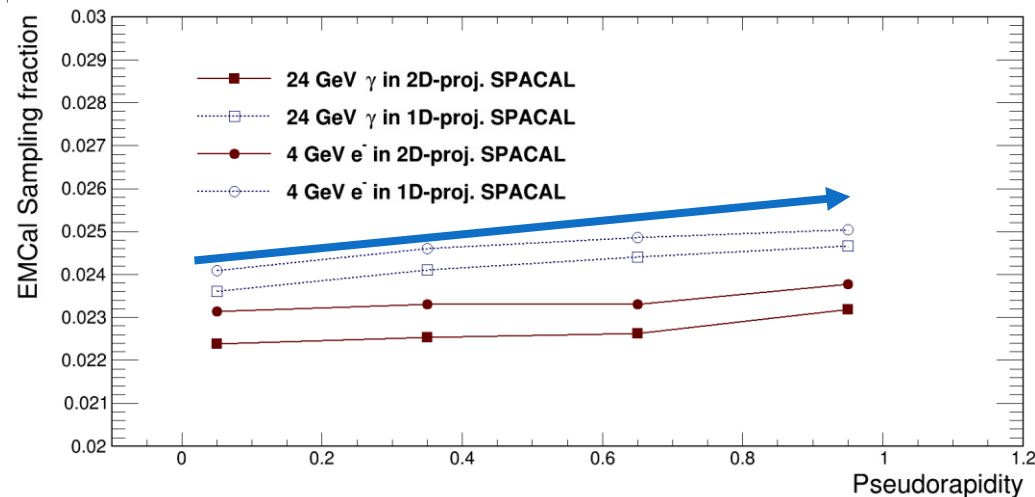
	4 GeV	8 GeV	16 GeV	25 GeV	32 GeV	40 GeV	50 GeV	60 GeV
pion	32.1%	39.8%	67.2%	85.7%	91.9%	94.6%	96.5%	97.2%
electron	63.7%	56.4%	26.1%	8.9%	3.7%	1.6%	0.6%	0.3%
muon	4.2%	3.8%	6.7%	5.4%	4.4%	3.8%	2.9%	2.5%

CALICE test, cited via FTBF cite (<http://ftbf.fnal.gov/>)



Needed from test beam: Electron response

- ▶ Linearity and resolution
- ▶ Also for tapered SPACAL, energy scale VS indenting angle

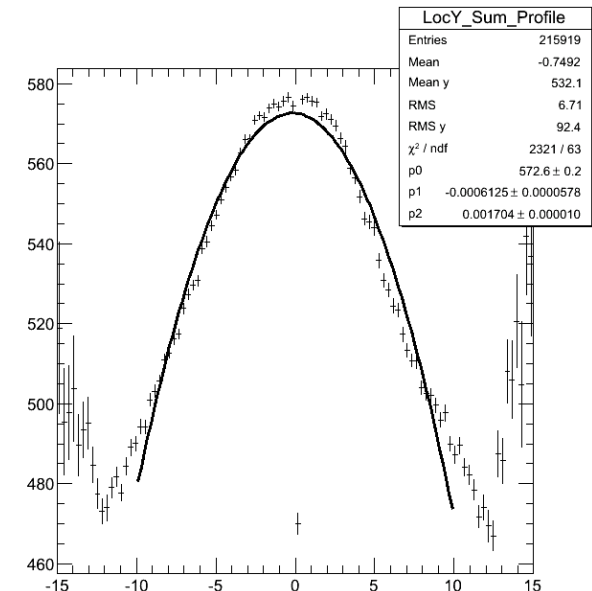
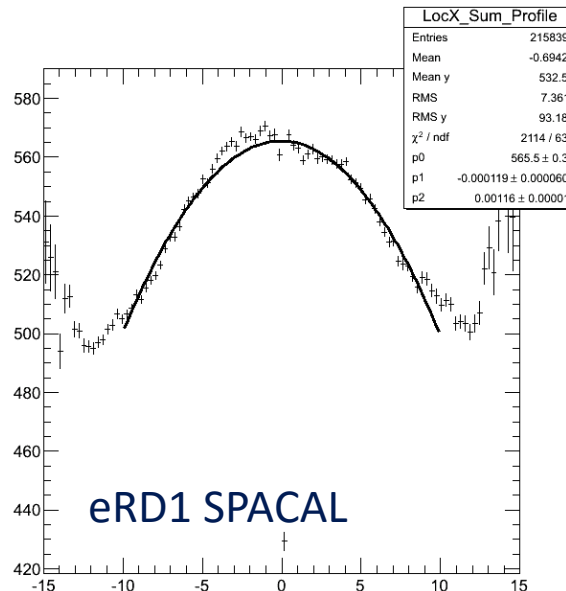
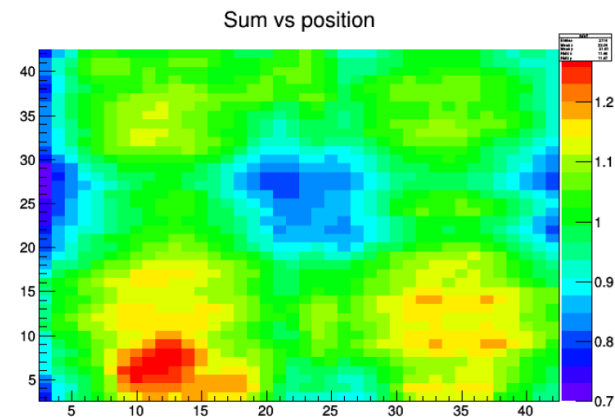


Needed from test beam:

Position response

- ▶ Quantify lateral positional dependence via photon collection eff. and fiducial area at the edge
- ▶ Verify longitudinal position dependence via fiber light attenuation, possible damage and cladding light.
- ▶ Both associate with additional constant term and high energy performance

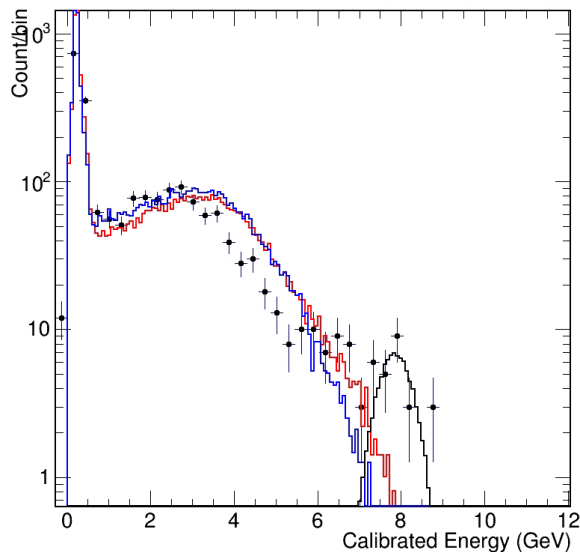
eRD1 SPACAL, UV photon scan



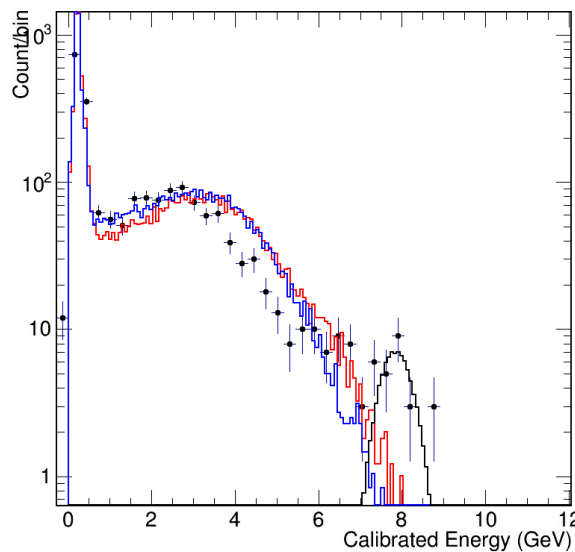
Needed from test beam: Constraint hadron model

Hadron response are open for many tunings, need clean hadron data to do so
Again, any proton/anti-proton component would behave very differently

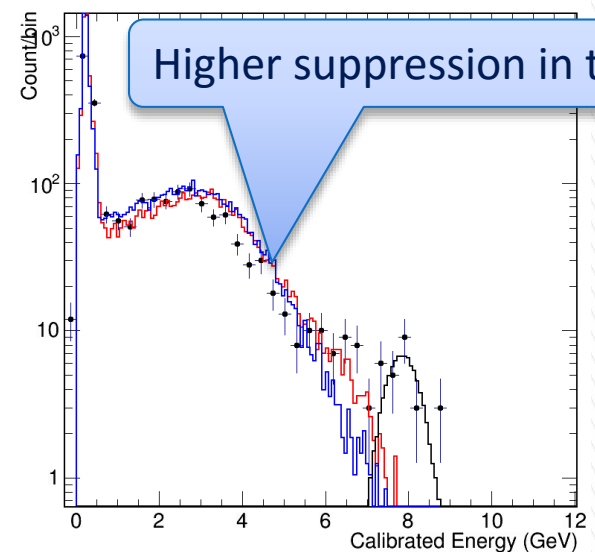
Pion- (red) K- (blue) e contain. (black) Sim VS data



Pion- (red) K- (blue) e contain. (black) Sim VS data



Pion- (red) K- (blue) e contain. (black) Sim VS data



Default configuration
production threshold of 1mm,
Birk constant = 0.00794 cm/MeV

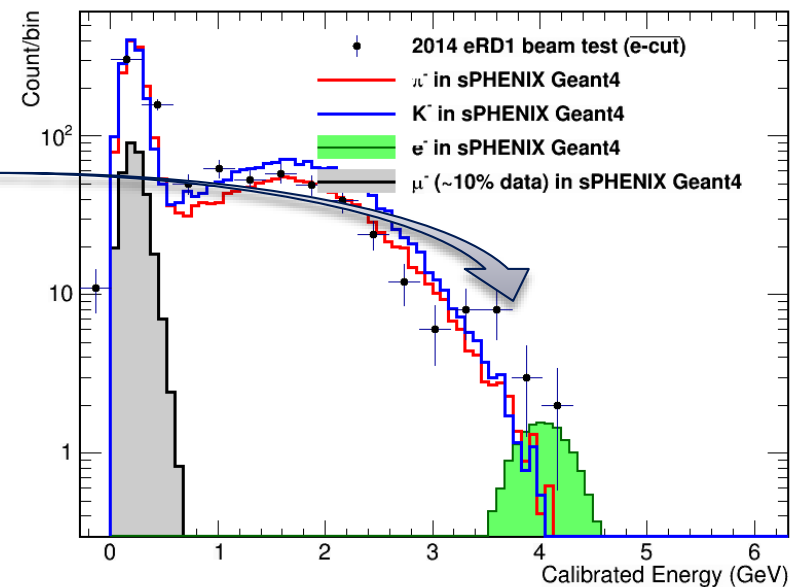
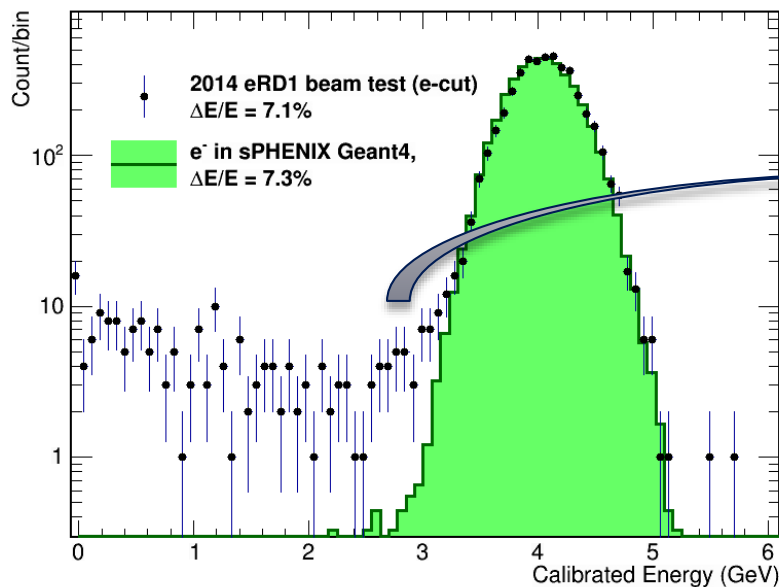
Baseline configuration
+ production threshold of 1 μm

Baseline configuration
+ CALICE Birk constant
0.0151 cm/MeV

Needed from test beam:

Clean beam tagging to pin down rare hadron shower

- ▶ Beam background as illustrated in electron sample also expected in the hadron sample
- ▶ Unfortunately, we are looking for $<10^{-2}$ rare hadron shower

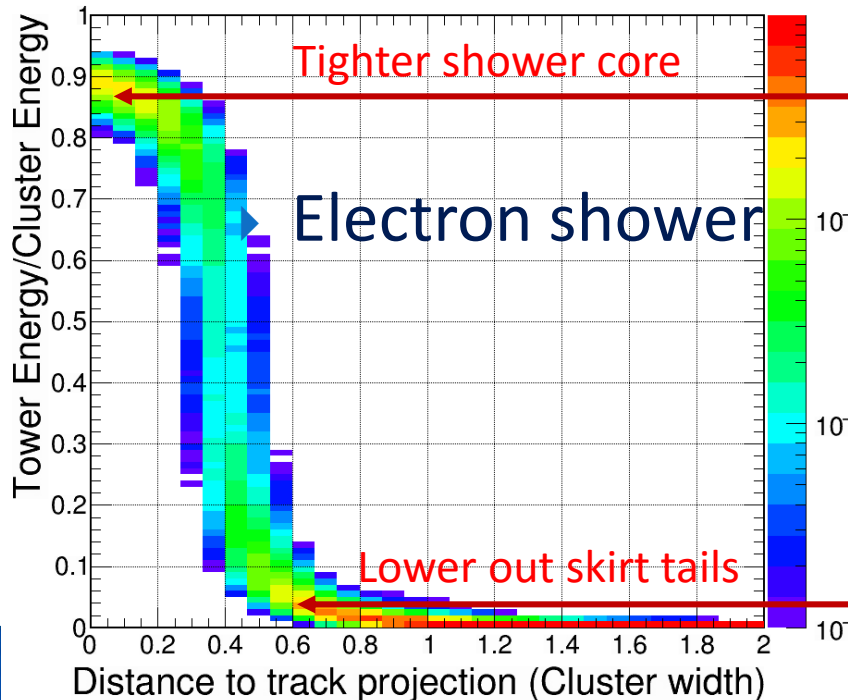


Needed from test beam:

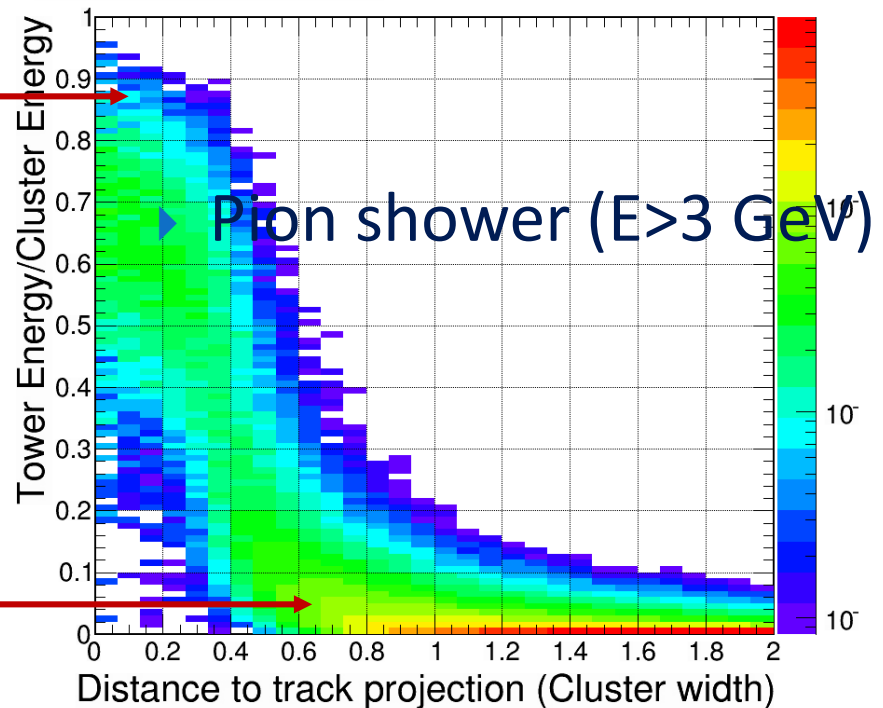
Shower shape verification

- ▶ For more advanced hadron rejection require shower shape analysis. Unfortunately it is more depending on reliability of hadronic shower simulation.
- ▶ Test beam data with tracking precision of $< \sim 2\text{mm}$ could pin down this uncertainty

CEMC Shower Shape Cluster width = 1.4 tower



CEMC Shower Shape Cluster width = 1.4 tower



Needed from test beam:

Tunneling effect in fiber view orientation

- ▶ In Geant4 we use straight fibers, however in reality they are likely to be wavy depending on construction procedure.
- ▶ For straight fibers, 20% of straight track would tunnel through the SPACAL, producing tails. Could be a problem for photon measurement
- ▶ Do we see that in prototype? Shall we make our fiber wavy in simulation?

